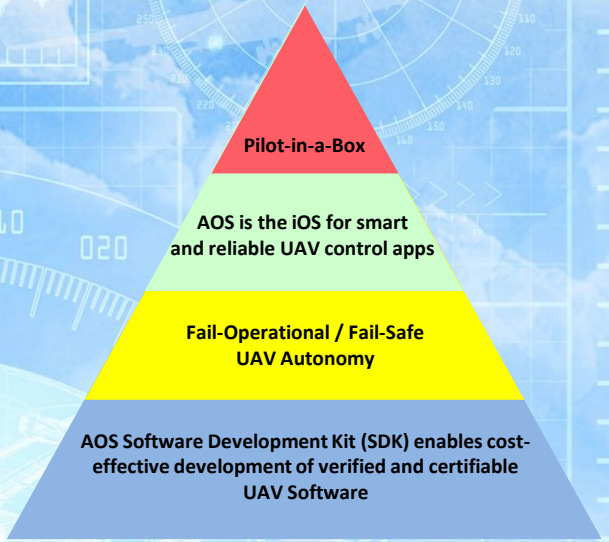
Autonomy Operating System for UAVs

Dr. Michael Lowry, PI (ARC)
Dr. Anupa Bajwa, Co-I (ARC)
Patrick Quach, Langley Lead
Professor Gabor Karsai, Vanderbilt
Professor Kristen Rozier, Iowa State
Professor Sanjai Rayadurgam, Univ. Minnesota

AOS Fact Sheet

- AOS is an open architecture for smart UAV flight software leading to Autonomy.
- The foundation is NASA Core Flight Software. Heritage of over 22 successful space missions, built for flight certification.
- Small Business Participation.
- Integrated Artificial Intelligence with the goal of achieving acceptable pilot behavior independent of remote ground crew.
- Open Source December 2017



AOS Project: NASA Feasibility Study

- The NASA ARMD AOS4UAV project is a 2 year feasibility study ending December 2017. Three assessment criteria:
  - 1: Open standard archetype for verifiable and certifiable UAV autonomy flight software.
  - 2: Reusable software platform and verification technology that enables development and certification of a wide range of UAV autonomy apps.
  - 3: Assess whether UAVs can safely and reliably fly themselves, behaving as a certified pilot.

Goal: AOS will become the iOS for Intelligent UAVs

Feasibility Study

A representative subset of UAV smart apps has been developed

NASA's space-heritage, reusable Artificial Intelligence engines are being integrated with CFS/cFE

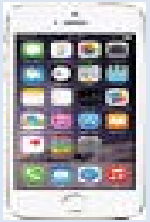
Verification is done through processor-in-the-loop (PIL), hardware-in-the-loop (HIL), and flight tests for V&V of AOS and autonomy apps

Post-Study

AOS will be refined from experimental software to a qualified and open-source platform for UAV flight software

Rapidly expanding number of UAV smart *Apps* revolutionizes civilian UAVs

Outcome



Similar to Apple's iOS, AOS will:

- enable rapid development of *Apps* with a low barrier to entry
- reliably support a large developer community
- apply to a wide range of hardware platforms.

AOS Open Architecture

Autonomy Apps
(Pilot-in-a-Box)

Plexil Procedures

Automated Reasoning

Diagnostic/Prog Models

Autonomy Executive (task prioritization)

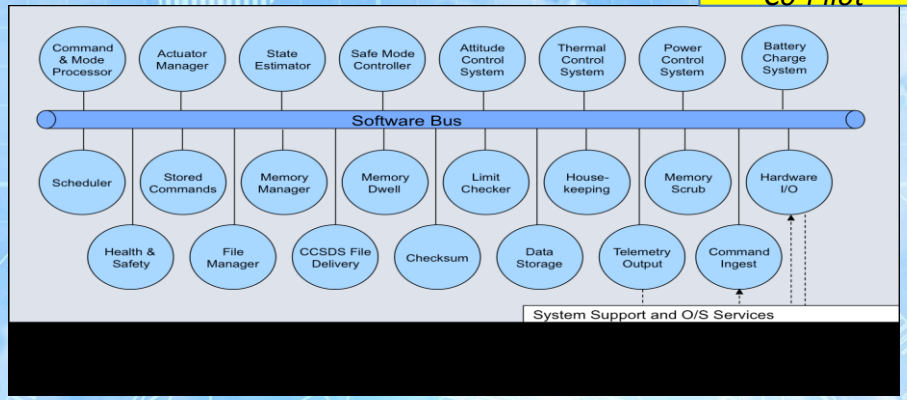
Knowledge bus (contingency plans, dynamic models)

AI: SMT Planner

AI: Plexil

AI: Diag/Prog

AI: Runtime Verification *Intelligent Co-Pilot*



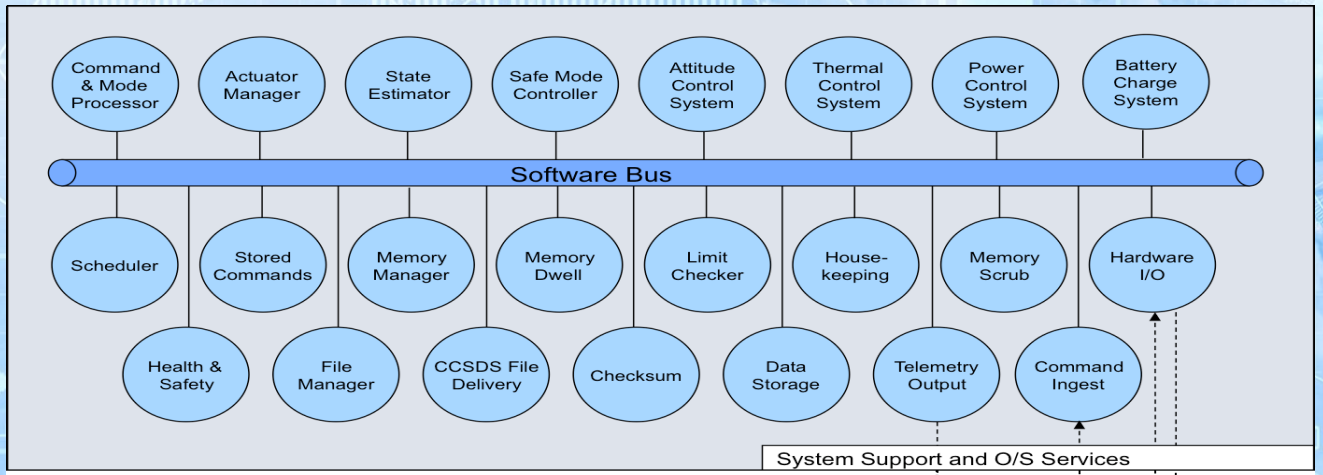
Blue – Heritage from NASA Space adapted for UAV domain.

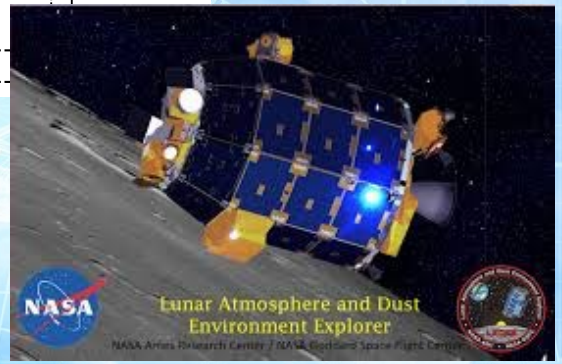
Red – NASA ARMD funded software subsystems and knowledge-bases to enable UAV Autonomy.

Yellow – Artificial Intelligence engines.

Green – Plug-in slots for new autonomy apps from open-source UAV community.

Core Flight Software





NASA SBIR/STTR Technologies

A2.02-7076 - Windhover Unmanned Aircraft Systems (UAS) Software Ecosystem

PI: Mathew Benson
Windhover Labs - League City, TX

Identification and Significance of Innovation

As autonomous UAS operations push against the FAA line-of-sight requirement, pilot intervention is replaced with onboard intelligence to sense and avoid trouble. The software making these decisions must be developed and tested to standards that ensure reliability and safety. Robust development, test, and operations tools ensure quality development, adequate testing, and insightful operations of UASs. Windhover Labs proposes to build upon their Phase I efforts to create a complete ecosystem of flight and ground software, as well as processes and standards for achieving the levels safety needed for operations of small UASs.
Application developers building on the Windhover infrastructure use industry standard IT practices to develop their applications. The entire Windhover tool chain is then used to create robust, multi-level test campaigns for verification and validation. These applications are built upon the pedigree of the Windhover framework using the same tool chain Windhover uses enabling an exponential rate of innovation in the UAS market.

Estimated TRL at beginning and end of contract: (Begin: 6 End: 8)

Technical Objectives and Work Plan

One year of Agile sprints will incrementally build an open, expandable Windhover UAS software ecosystem including: Airliner, Commander, Workshop, Trainer, Flightline Apps, Hangar, Checkride certification program.
1. UAS avionics platform providers have a robust, full-featured flight software framework to provide with their avionics. (Airliner, Hangar)
2. UAS operators have a scalable operations solution that allows them to manage their fleet of UASs. (Commander)
3. UAS application developers have a full featured IDE for maintaining their software contributions to the ecosystem. (Workshop, Hangar)
4. UAS enterprise users and service providers have the ability to extend and expand the usefulness of their UASs using Python and JavaScript. (Workshop)
5. UAS application developers are able to test their applications to ensure safe, reliable operations. (Workshop, Trainer, Checkride)
6. UAS enterprise users and service providers are able to deploy their user applications to the onboard, ground based, and/or cloud based application engines. (Airliner, Commander, Hangar)
7. UAS application developers collaborate with others, share applications, and profit from their contributions to the Windhover ecosystem. (Hangar)
8. All software in the Windhover ecosystem has a documented pedigree associated with its classification and certification level. (Checkride)

NASA Applications

* Unmanned Traffic Management for UAS in low-altitude airspace requires robust FSW and integrated ground solutions like these to be successful
* Autonomy Operating System, which is building smart drones with CFS and artificial intelligence reasoning engines, will benefit from the tools and certification efforts targeting CFS
* Human Exploration Mission Directorate has embraced the use of CFS and can benefit from certification and tools compatible with CFS
* Can use Windhover/Aerotenna powered UASs to map low altitude airspace

Non-NASA Applications

* Windhover Labs entered into strategic partnership with Aerotenna Inc. which includes a $25,000 commitment to Phase II for sensor integration
* Pursuing joint projects involving Intel Aero / Qualcomm Snapdragon avionics and Purdue Aerial Robotics Team
* App store delivers Windhover and 3rd party software with revenue sharing
* Windhover users will purchase expert support to help them achieve goals

Firm Contacts

Mathew Benson
Windhover Labs
2115 Castle Drive
League City, TX, 77573-4947
PHONE: (832) 640-4018

Towards AOS Autonomous Pilot

- Instrument-rated pilot
- Co-pilot
- ATC interface manager
- System manager
- Mission manager

Humans presumed competent and trustworthy after demonstration of task knowledge.

- Pilot-in-a Box
- R2U2
- Natural lang. dialogue capability
- Diagnostic reasoner
- Supervisory autonomy

AOS explains decision making based on transparent models and traceable reasoning.

Autonomy Technology for Artificial Intelligence Pilot Competencies

✓ Procedural Knowledge

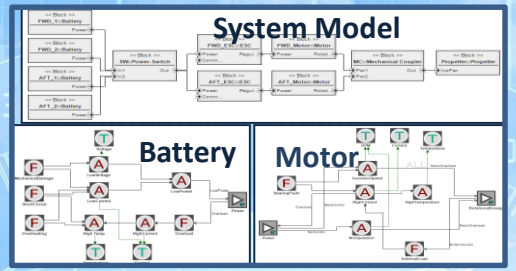
Practical Test Standards: *Areas of operation and tasks in which competency must be demonstrated for issuance of a pilot certificate.*

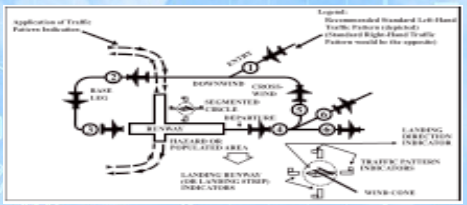
❑ Situational Awareness

✓ Vehicle
Air Traffic

❑ Thinking Ahead of the Plane

- *Plan ahead and setup for next part of flight.*
- *What-if contingency planning.*
- *Managing off-nominal situations to avoid cascading emergencies and loss of life.*





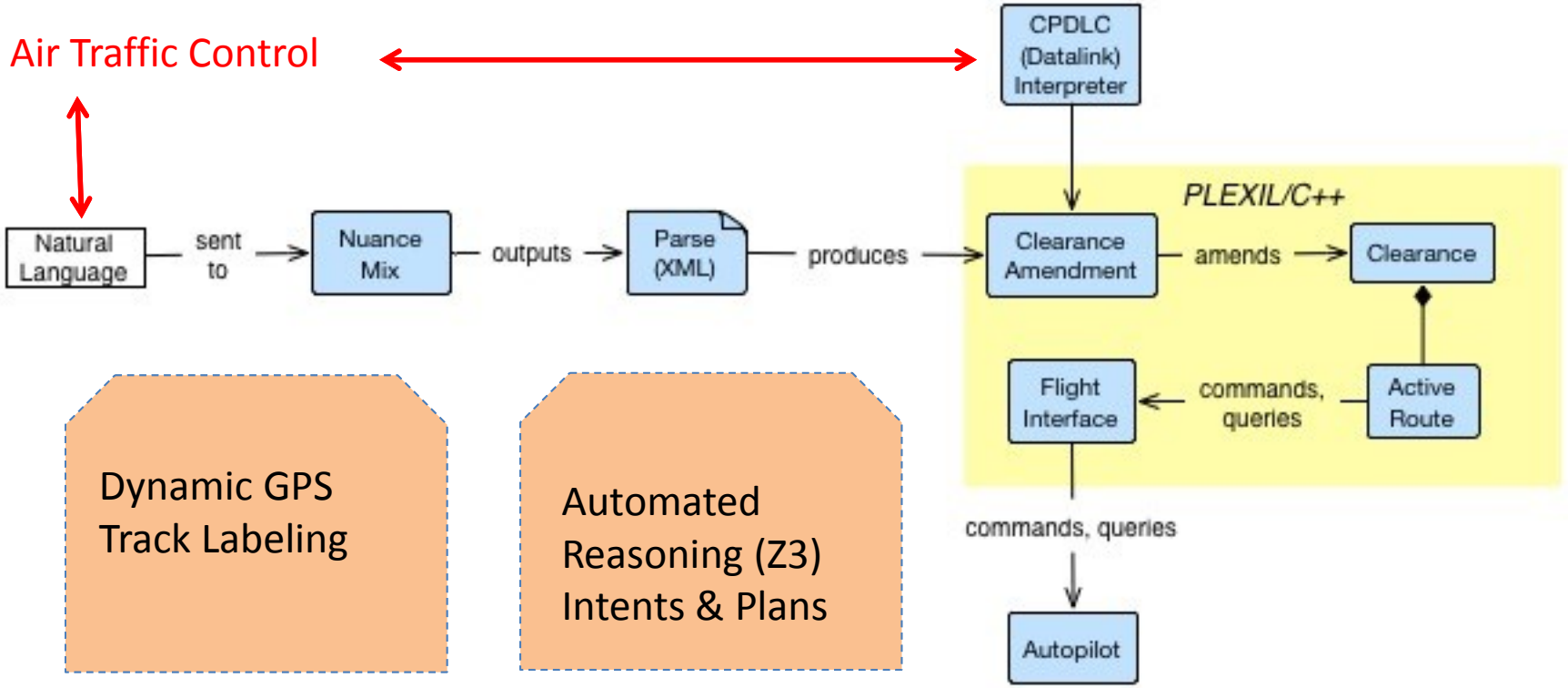
Example: Pilot Procedural Knowledge for FAA Lost Comm

Route. (1) Last ATC clearance received; (2) If being radar vectored, by the direct route to fix specified in vector clearance
(3) Route expected in a further clearance; or
(4) In the absence of an assigned route or a route that ATC has advised may be expected in a further clearance by the route filed in the flight plan.
Altitude. At the HIGHEST of the following altitudes or flight levels FOR THE ROUTE SEGMENT BEING FLOWN: (1) The altitude in the last ATC clearance received;
(2) The minimum altitude for IFR operations; or
(3) The altitude or flight level ATC has advised may be expected in a further clearance.

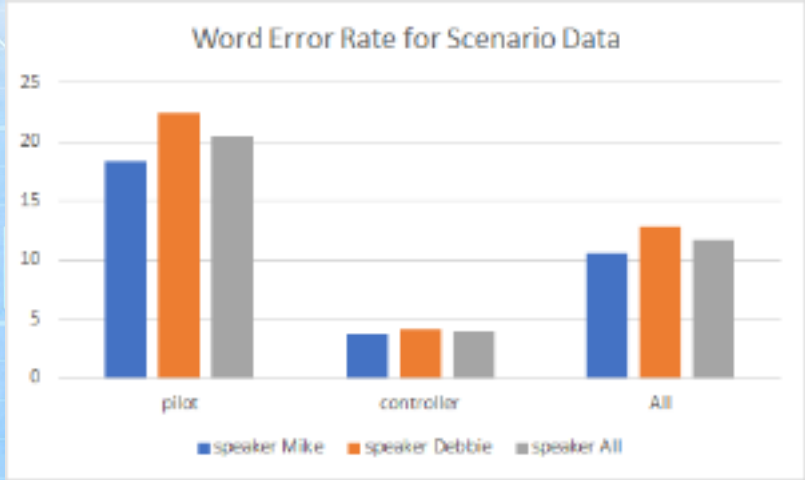
Clearance: RT 060 1 mile after depart, RV SJC, climb 3000, expect 5000 10 min after depart

[4] 007UAV : Received EFC for time 17 ; Alt = 5000
[4] 007UAV : RT 060
[5] 007UAV : Setting altitude: 3000
[8] ATC: Turn Heading 120
[9] 007UAV: Heading 120
[10] 007UAV: Radio check failed.
[11] 007UAV : Beginning lost comm procedure…
[12] ATC: Fly direct Sunol
[12] 007UAV : Squawking 7600
[13] ATC: NORDO 007UAV
[13] 007UAV: Attempting to hail ATC
[13] 007UAV: Attempting to visually locate airports..
[14] 007UAV: Set waypoint SJC
[17] 007UAV: setting altitude to 5000, per EFC
[24] 007UAV: Reached waypoint: SJC
[24] 007UAV: Setting waypoint per flight plan: Sunol

AOS Interaction with Air Traffic Control



Natural Language



Initial training on controller utterances:
3-4% word error rate.

Out of the box on pilot utterances:
20% error rate.

Dense Airspace Situational Awareness: KPAO Terminal Area

AOS will understand the intent of ATC and other aircraft to seemlessly integrate into the traffic flow and fly according to ATC clearances with situational awareness of other traffic and sequencing.

Autonomous Emergency Management

Bad day Scenario for 007JB

Electrical Over-current

Trouble-shooting

Intrusion from another aircraft into safety zone

Detect and Avoid maneuvers

Engine malfunction

Diagnostic/recovery procedures

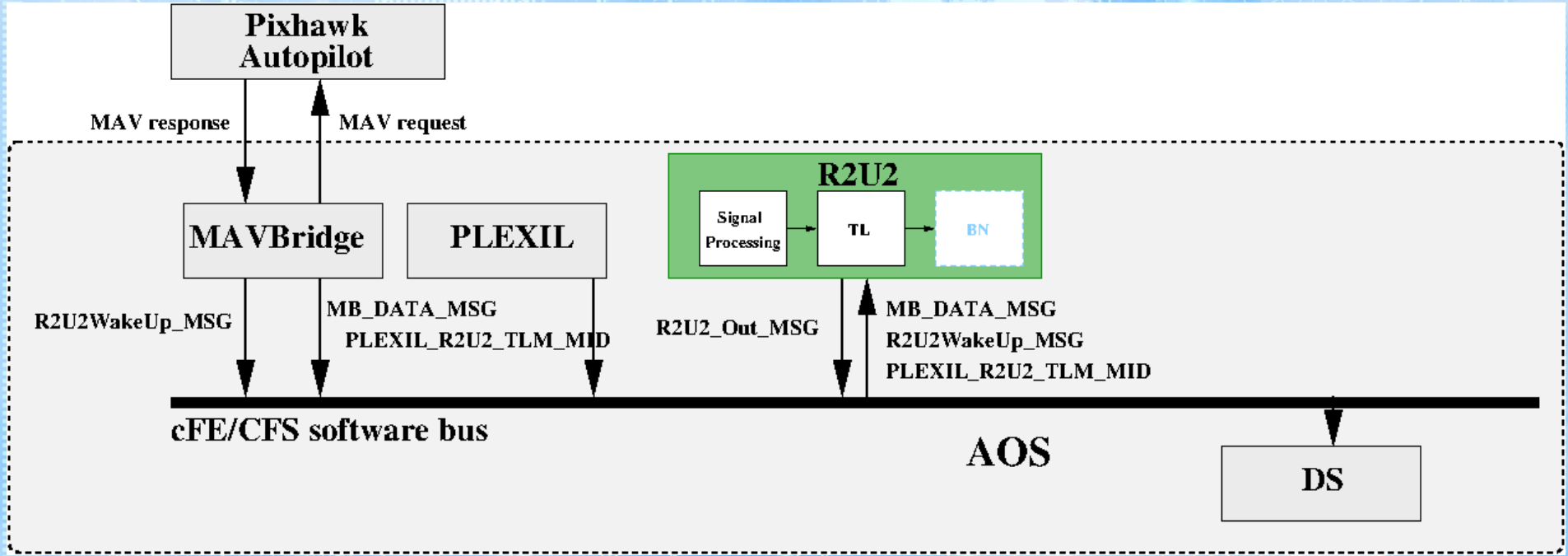
Smoke in cockpit

Decision: Continue Flight, Land as soon as practical , Ditch in nearest safe zone

- Onboard prognostics and diagnostics
- Encode POH emergency procedures
- Fault assessment and effect prediction
- Prioritize and (re)schedule tasks – scheduling algorithm interfaced to cFE and Plexil.
- Replan for unforeseen situations.

Flight tests scheduled for late spring with ground-based fault injection on HIL.

AOS Failure Detection, Diagnosis, and Mitigation with the Realizable, Responsive, Unobtrusive Unit (R2U2)



AOS Take-Away

- Core Flight Software has successfully transitioned from Space to Aviation.
- AOS is seeking self-funded collaborators to develop smart UAV apps this summer.
- Open source for UAVs will be available within the year, both AOS and Windhover.